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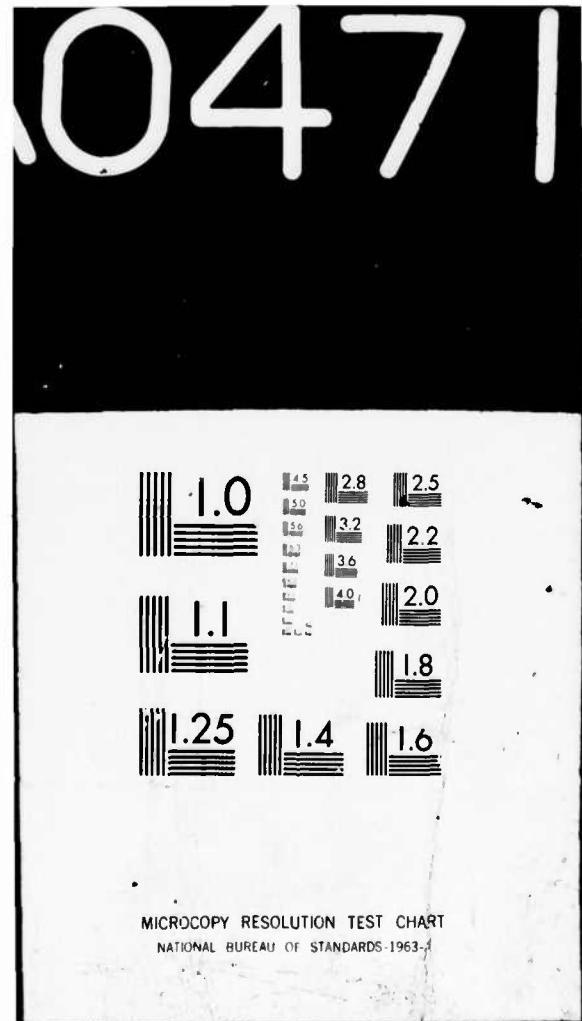
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NRL GFCS
Final Report

D. R. Woods
F. G. Smith
L. W. Chaney
W. L. Flowers
R. E. Meredith
J. P. Walker



11 June 1975 to 30 September 1976

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Naval Research Laboratory
Washington, D. C.

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Contract N00173-75-C-0627



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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NRL GFCS. Final Report		5. TYPE OF REPORT & PERIOD COVERED Final Report. 11 June 1975 - 30 Sep 1976
6. AUTHOR(s) D. R. Woods, F. G. Smith, L. W. Chaney, W. L. Flowers, R. E. Meredith and J. P. Walker		7. PERFORMING ORGANIZATION REPORT NUMBER SAI-76-008-AA
8. CONTRACT OR GRANT NUMBER(s) N00173-75-C-0627		9. PERFORMANCE ORGANIZATION NAME AND ADDRESS Science Applications, Inc. ✓ P. O. Box 328 Ann Arbor, MI 48107
10. CONTROLLING OFFICE NAME AND ADDRESS Naval Research Laboratory Washington, D. C.		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12. 26p.		12. REPORT DATE October 1976
13. NUMBER OF PAGES 23		14. SECURITY CLASS. (of this report) Unclassified
15. DECLASSIFICATION/DOWNGRADING SCHEDULE		16. DISTRIBUTION STATEMENT (of this Report) APPROVED FOR PUBLIC RELEASE DISTRIBUTION UNLIMITED
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		D D C NOV 28 1977 REF ID: A651140 F.
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Gas Filter Correlation Integrated Water Vapor Measurement		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A Gas Filter Correlation Spectrometer has been constructed to measure the integrated atmospheric water vapor over a 5 km path.		

390 938

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1. INTRODUCTION

The Gas Filter Correlation Spectrometer (GFCS) constructed on this contract is an infrared instrument to measure the integrated atmospheric water vapor content over a multi-kilometer path. The unit has been designed to operate in the NRL IMORL field measurement vans. A source unit is placed in the transmitter van. The GFCS unit, a calibration source unit, and an electronics unit are placed in the receiver van which is 5 kilometers away from the transmitter van. The source unit provides an infrared signal which is sent through the 5 kilometer atmospheric path by the transmitter van optics to the receiver van optics. The GFCS unit then correlates the spectral structure of the received signal with the spectral structure of water vapor to determine the integrated atmospheric water vapor content.

The GFCS technology has, in the past, been used to make local measurements of trace gases. However, this is the first instrument to be used to measure a concentrated gas (i. e., water vapor), over a long atmospheric path. The instrument was constructed to evaluate this new technology's potential for use as a path diagnostic instrument for eventual shipboard deployment, while simultaneously providing support for NRL's field measurement effort.

2. CONCEPT OF OPERATION

The GFCS concept is quite simple, although the detailed physics may be difficult to visualize. The term gas filter refers to the use of the complex infrared absorption spectra of a gas, in this case water vapor, as an infrared filter. Correlation refers to the spectral correlation between the gas filter and the infrared absorption spectra of the same gas in the atmosphere. The principle of operation is given by Equation (1) and Figure 1.

$$M = \frac{T_{ac} - T_a T_c}{T_{ac} + T_a T_c} \quad (1)$$

where

M is the instrument signal caused by water vapor.

T_a is the average transmission of the atmospheric water vapor over the infrared bandpass of the GFCS.

T_c is the average transmission of the GFCS water vapor sample cell over the infrared bandpass of the GFCS.

T_{ac} is the average transmission of a combination of atmospheric water vapor and sample cell water vapor over the infrared bandpass of the GFCS.

Equation (1) expresses the water vapor signal in terms of the degree to which it modulates the source signal. This degree of modulation is the value actually measured by the GFCS. The water vapor measurement signal M arises from the fact that the average transmission of the combination of the atmospheric and sample cell water vapor (T_{ac}) is greater than the product of individual average transmissions T_a and T_c , when water vapor is present in the atmosphere. This occurs because of the correlation between the water vapor absorption line spectrum in the atmosphere and the sample cell. This principle is illustrated in Figure 2.

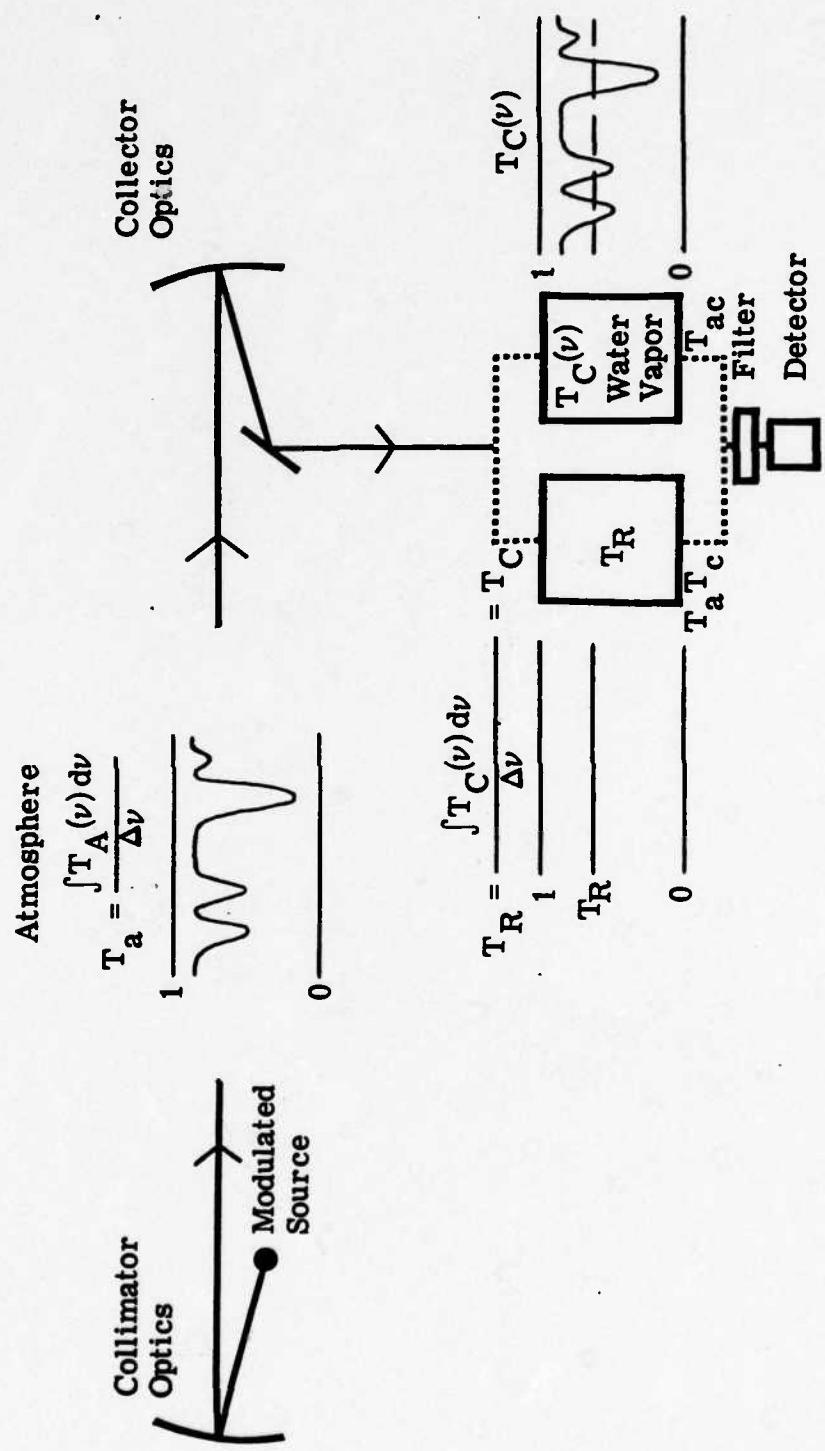
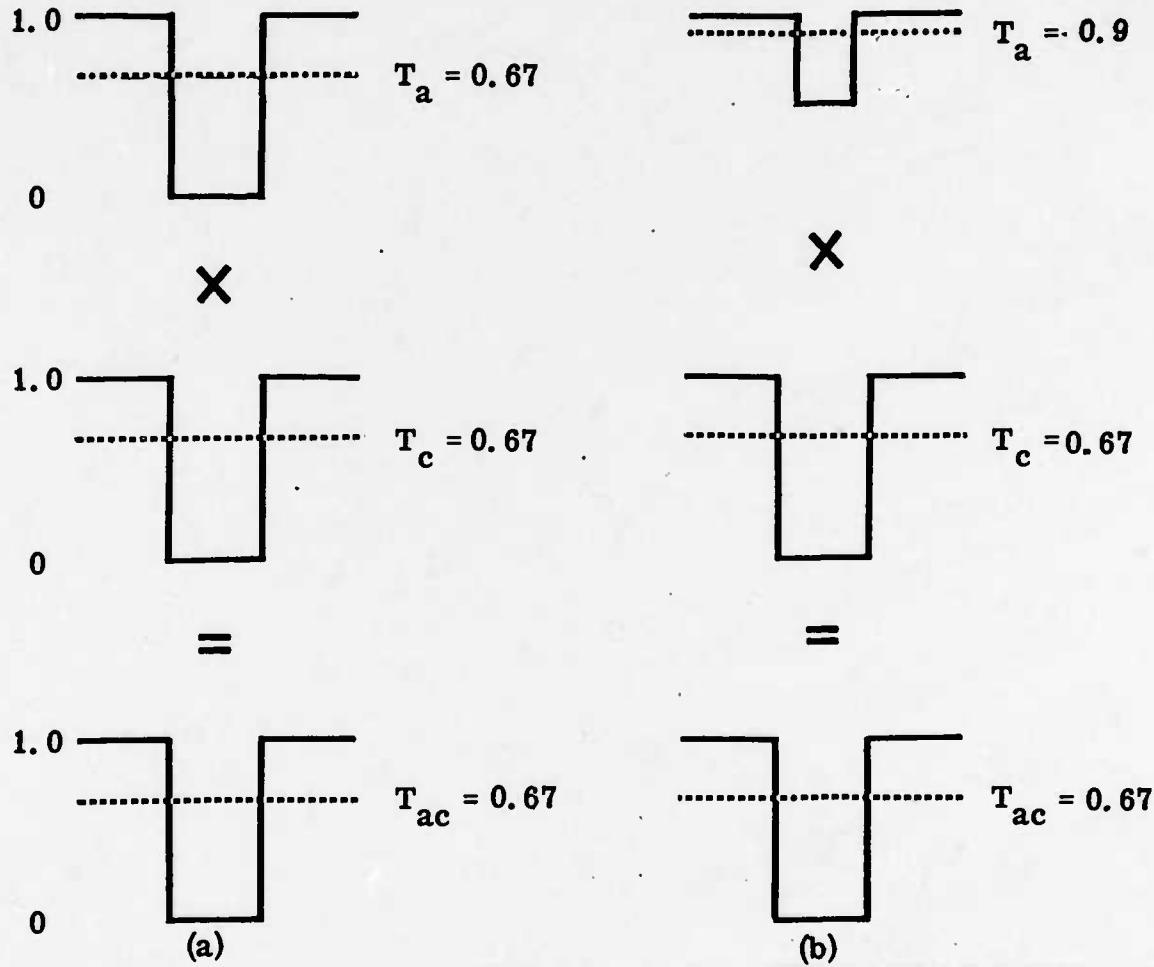


Figure 1. Basic GFCS Operation



$$(a) T_{ac} - T_a T_c = 0.67 - 0.67 \times 0.67 \\ = 0.2211$$

$$(b) T_{ac} - T_a T_c = 0.67 - 0.9 \times 0.67 \\ = 0.0670$$

Figure 2. Simplified Example of the Correlation Principle

$$T_{ac} \geq T_a T_c \quad (2)$$

where

$$T_{ac} = \frac{1}{\Delta\nu} \int_{\Delta\nu} T_a(\nu) T_c(\nu) d\nu \quad (3)$$

$$T_a T_c = \left[\frac{1}{\Delta\nu} \int_{\Delta\nu} T_A(\nu) d\nu \right] \times \left[\frac{1}{\Delta\nu} \int_{\Delta\nu} T_C(\nu) d\nu \right] \quad (4)$$

In the actual GFCS, the source signal is initially chopped at 750 Hz to allow the signal processing electronics to discriminate between it and other signals. This beam is alternately passed through an HDO cell to obtain the combined cell atmospheric path transmission T_{ac} , and passed through a reference attenuation path with a constant transmission adjusted to the average water vapor cell transmission [$T_R = T_c$] to obtain the product $T_a T_c$. After the signal is modulated by this procedure it is imaged onto a detector.

3. GFCS DESCRIPTION

The Gas Filter Correlation Spectrometer (GFCS) consists of four subsystems: (1) the modulated source, which is placed in the NRL IMORL transmitter van; (2) and (3), the calibration source and the basic GFCS unit, which are placed in the receiver van; and (4) the electronics package, which can be placed in either the receiver van or an adjacent van. These are shown schematically in Figure 3.

The general characteristics of the system are given in Table 1. Note the long warm-up time required to heat the HDO sample cell to its operating temperature. The cell must be heated because the water vapor in the cell would condense at room temperature.

3.1 Source

A drawing of the source appears in Figure 4 with a description of the various numbered components given in Table 2. An infrared source is imaged onto an optical chopper and subsequently focused through a coupling mirror to the focal point of the NRL transmitter telescope. The power supply for the source element is mounted inside the source cover. A power switch turns on the source element. A second switch turns on the chopper and moves it into the beam.

3.2 Calibration Source

The calibration source is designed to set on top of the GFCS. With no water vapor in the path, the calibration source provides a signal which is used to balance the average attenuation of the sample and reference paths. A water vapor cell is inserted into the beam to calibrate the response of the system.

Figure 5 and Table 3 provide a description of the calibration source. It consists of an infrared source, an optical chopper, and

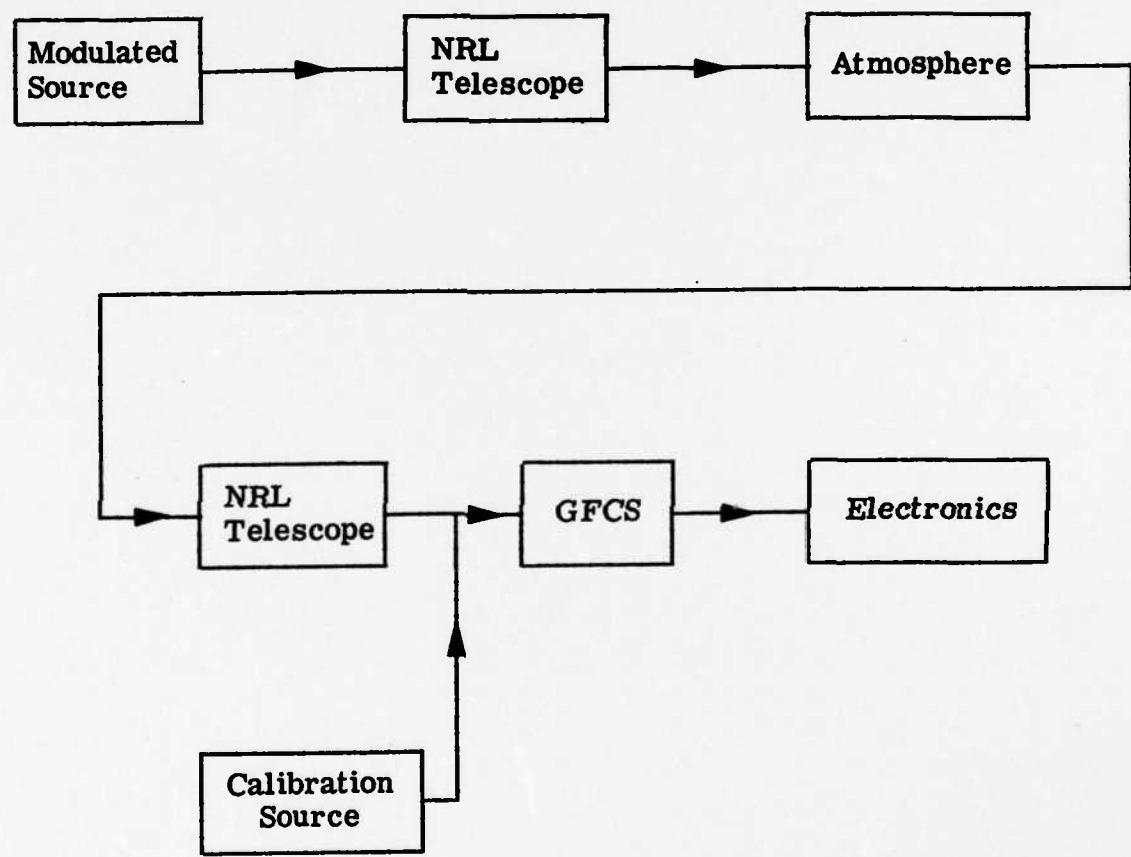


Figure 3. GFCS Block Diagram

Table 1.
General GFCS Characteristics

	Source	Calibration Source	GFCS	Electronics
Length (cm)	76. 2	153. 09	162. 88	31. 12
Width (cm)	30. 8	50. 90	58. 18	22. 90
Height (cm)	20. 3	35. 56	41. 91	30. 50
Weight (lb)	30	235	250	20
Power (watts)	70	NA	NA	250
Temperature (°C)	0-40	0-40	0-40	0-40
Warm Up Time (min)	5	5	120	5
Environment	Sheltered	Sheltered	Sheltered	Sheltered

Table 2.
Source Components

- 1 Source Element
- 2 Concave Mirror
- 3 Optical Chopper
- 4 Concave Mirror
- 5 Flat Mirror
- 6 Exit Port
- 7 NRL Coupling Mirror
- 8 Power Switch
- 9 Cover and Base

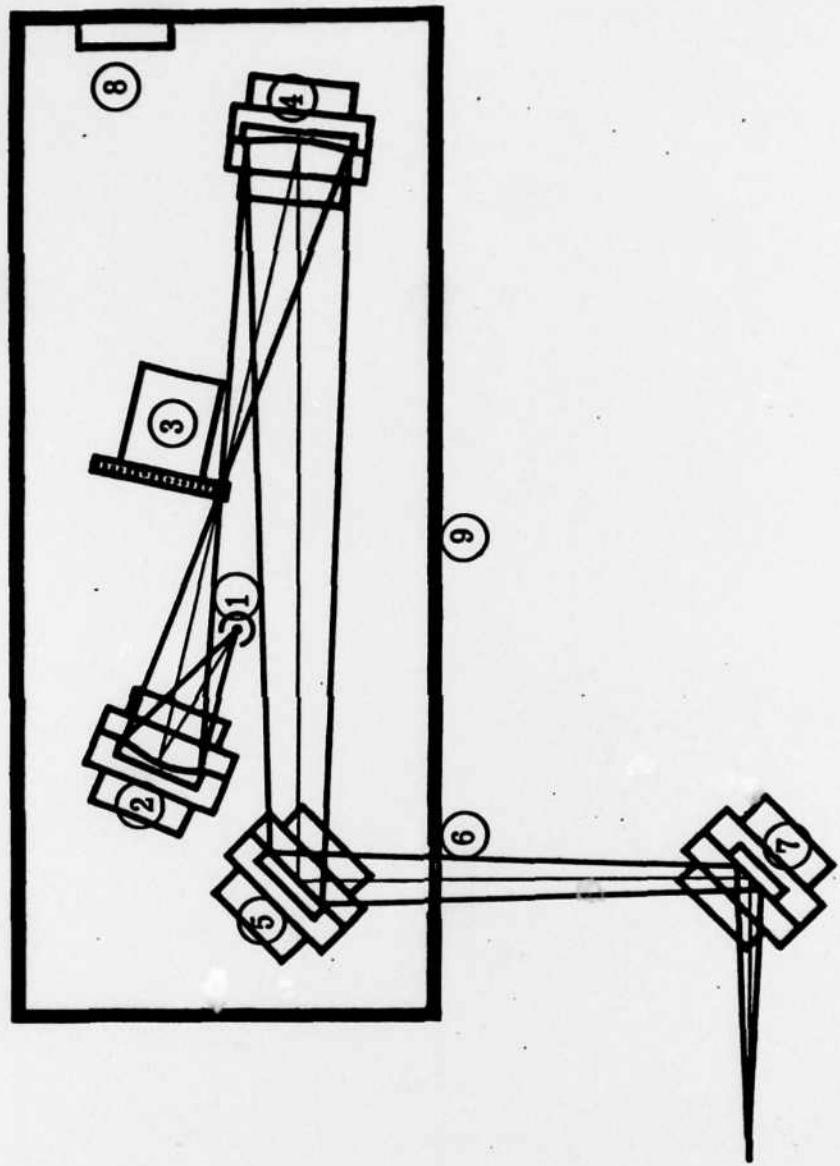


Figure 4. Source Diagram

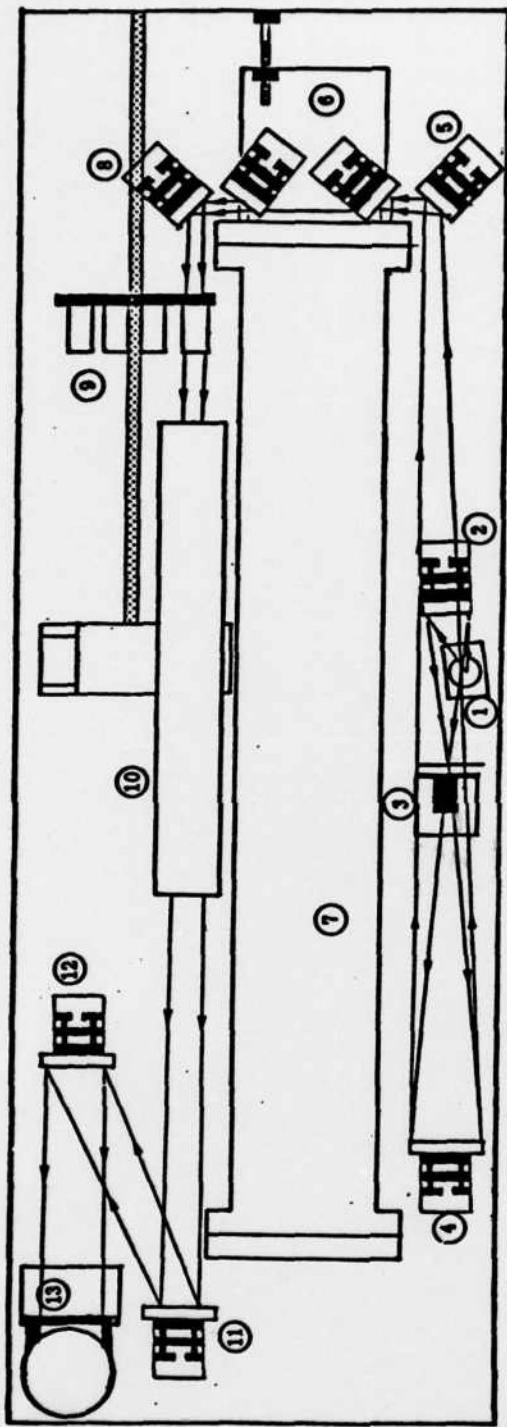


Figure 5. Calibration Source Diagram

Table 3.
Calibration Source Elements

- 1 Source Assembly**
- 2 Collecting Mirror**
- 3 Chopper**
- 4 Concave Mirror**
- 5 Flat Mirror**
- 6 Dovetail Slide and Folding Mirror Assembly**
- 7 White cell**
- 8 Flat Mirror**
- 9 Carrousel - Short Calibration Cells**
- 10 Long Calibration Cell and Dovetail Slide Assembly**
- 11 Flat Mirror**
- 12 Concave Mirror**
- 13 Flat Periscope Mirror**

optics to transfer the source image onto the entrance aperture of the GFCS. A movable mirror arrangement allows the beam to pass through the multiple pass water vapor calibration cell if desired.

This cell has been filled with a mixture of water vapor and dry air. The optical path length per pass is 1.003 meters. With changes in the number of passes, the water vapor absorption path can be adjusted to be equivalent to a 5 km atmosphere path for a wide range of humidities.

N_2O , CO and CH_4 calibration cells are mounted on a carrousel and a CO_2 cell is mounted on a dovetail slide. These can be inserted

in the beam to provide a calibration signal for the NRL SMI. Additional transfer optics serve to image the beam onto the entrance aperture of the GFCS.

The calibration source obtains its power from the GFCS. One switch on the calibration source turns on the source elements while the other turns on the chopper and inserts it into the beam. Thus it is possible to obtain either a modulated or unmodulated beam from the calibration source.

3.3 GFCS

A drawing of the GFCS portion of the instrument is given in Figure 6 accompanied by Table 4. NRL optics focus the incoming beam onto the entrance aperture of the GFCS. The beam enters under a diagonal beam splitter and is then reflected back to the beam splitter by a concave mirror with a field aperture on it. From the beam splitter the beam goes to a mirrored chopper which causes the beam to alternately pass through a heated water vapor sample cell and a reference path. The reference path attenuation is adjusted by changing the angle of an attenuator element. After the beam passes through the sample and reference paths, it is retroreflected back through the beam splitter to a series of mirrors which image the entrance aperture onto a field lens. The lens images the field aperture onto an infrared detector. The detector preamplifier is mounted in the GFCS. Signal detection and processing is performed in a separate electronics package which also provides the power for the sample cell heater, the temperature regulator circuit, the preamplifier, and the chopper. After processing, the water vapor DC voltage signal is returned to the GFCS and made available for monitoring by means of a BNC panel connector.

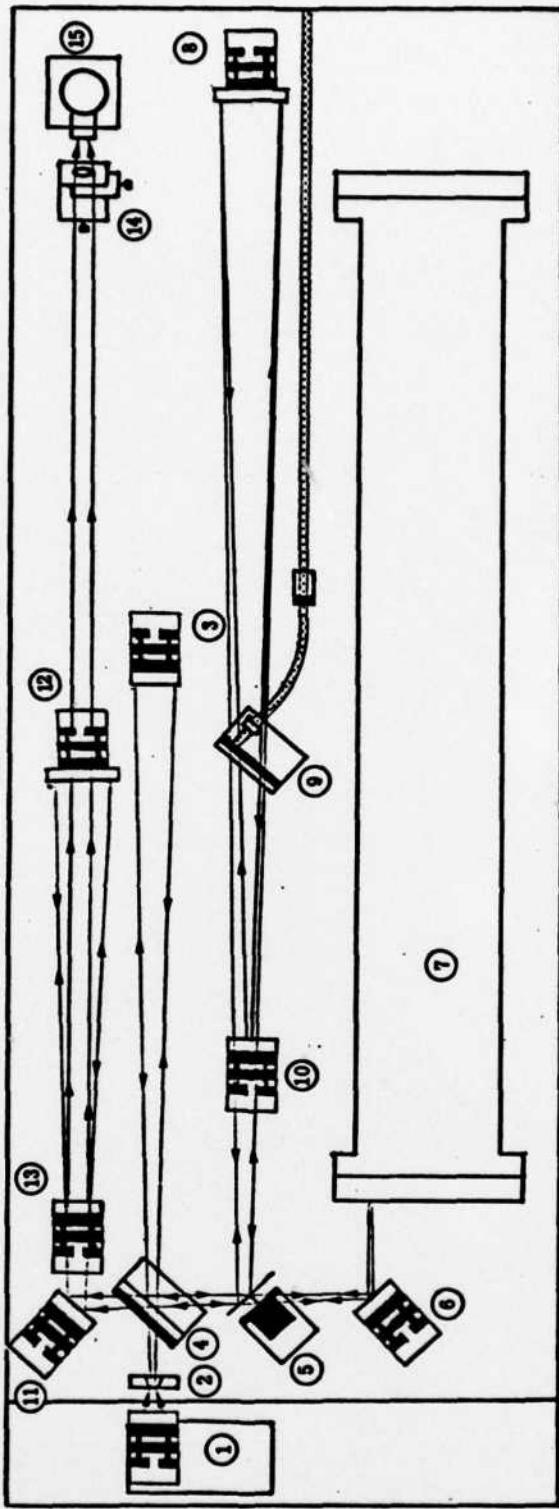


Figure 6. Gas Filter Correlation Spectrometer

Table 4.
GFCS Components

- 1 Dovetail Slide and Periscope Mirror Assembly**
- 2 Entrance Aperture**
- 3 Collecting Mirror, Incoming Beam**
- 4 Beamsplitter**
- 5 Mirror Chopper**
- 6 Flat Mirror**
- 7 Heated White Cell**
- 8 Concave Mirror, Reference Path**
- 9 Optical Attenuator for Balance Adjustment**
- 10 Concave Mirror, Reference Path**
- 11 Flat Mirror**
- 12 Concave Mirror, Combined Beams**
- 13 Flat Mirror**
- 14 Field Lens**
- 15 Detector Assembly**

3.4 Signal Processing Electronics

Signal Processing

The measured signal arises from the modulation of the signal envelope of the chopped infrared source. The modulation is the result of alternately passing the chopped source (which travels through the atmosphere) through a water vapor sample path and a reference path. The degree of modulation is then determined by electronically dividing the raw water vapor modulation signal by the reference or carrier signal to obtain the degree of modulation.

Electronics

A block diagram of the electronics package is given in Figure 7. The electronics consist of a preamplifier and variable gain amplifier to amplify the source signal. Then the signal is bandpass filtered and rectified by an absolute value module. A portion of this signal travels through a low-pass filter and drives the denominator of the voltage divider.

The rest of the rectified signal passes through a 45 Hz bandpass filter. An attenuator reduces the 45 Hz signal to the level required as input to the lock-in amplifier. The lock-in amplifier extracts the 45 Hz signal, rectifies it, and provides a DC output through a low pass filter. This signal is the numerator of the voltage divider.

The 10 V_{dc} output of the voltage divider drives a digital panel meter and a strip chart recorder. A 5000 ohm resistor voltage divider provides a 5 V_{dc} output for the NRL A/D converter.

3.5 White Cell Description

A white cell is a multiple traversal gas absorption cell designed to obtain a long optical path in a limited amount of space. A top view of the optics is given in Figure 8, where the cell is set up for 4 passes. The number of passes may be any integer multiple of 4 up to about 32, depending on the image size and the distance of the entrance and exit apertures from the edge of the front mirror.

In Figure 9 the image pattern on the front mirror is shown for the case of 20 passes. The number of passes is $(2N+1)$ where N is the number of images on the front mirror. The beam enters at 0, and is imaged by the right back mirror to 1. Then the left back mirror is adjusted to establish the number of passes and to cause the beam to exit at 10. In the GFCS White cell a retro-mirror has been placed

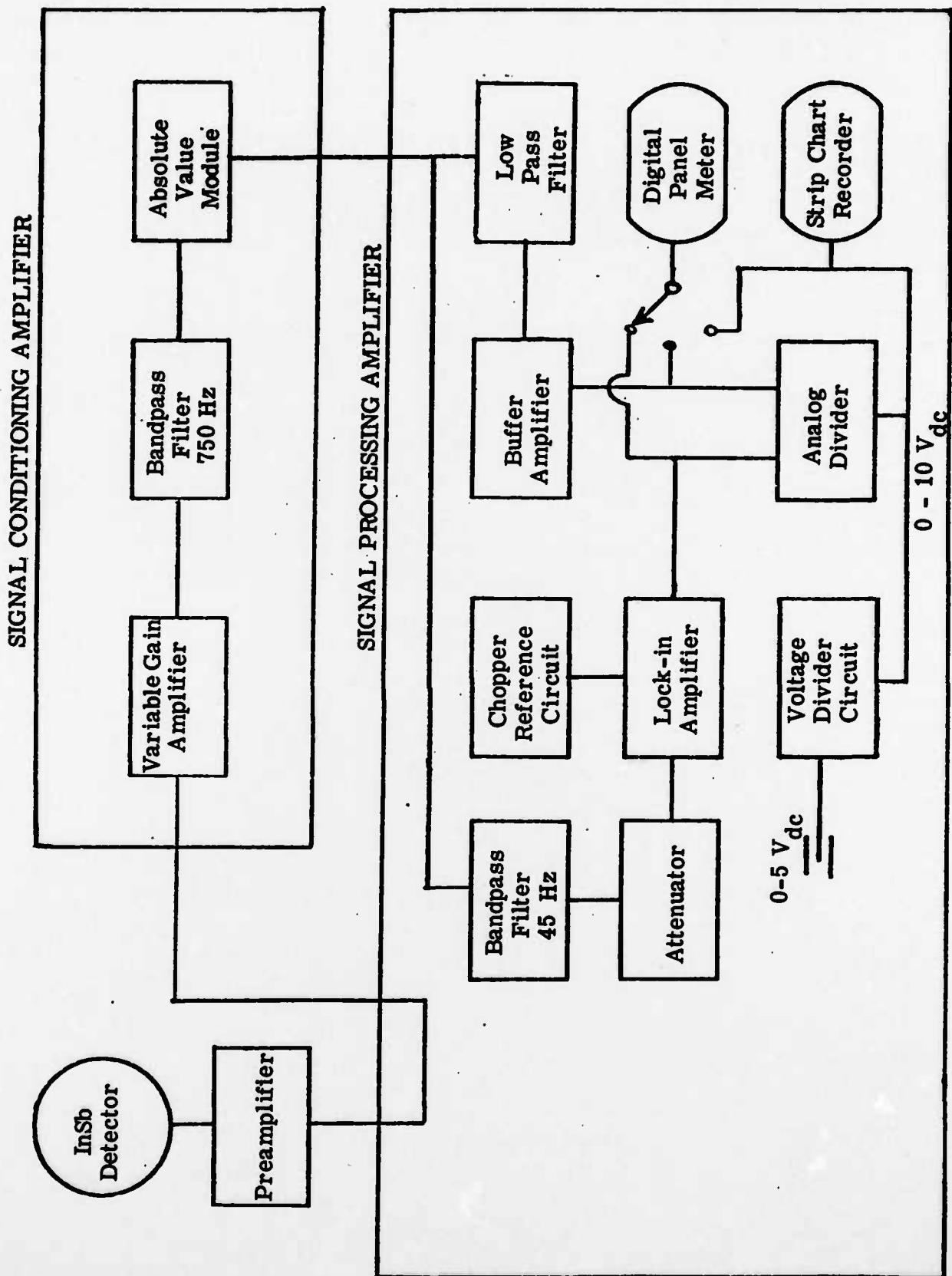


Figure 7. Electronics Block Diagram

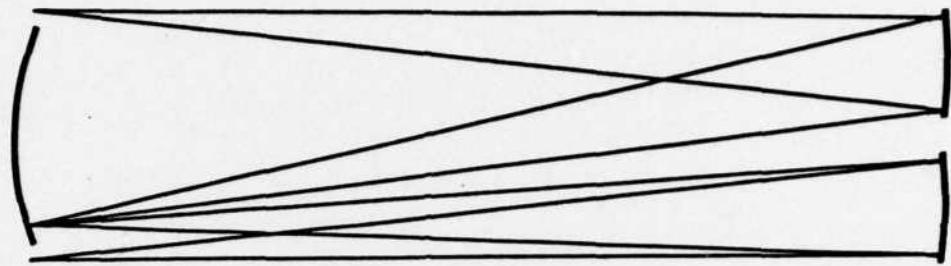


Figure 8. Top View of White Cell Showing Four Passes

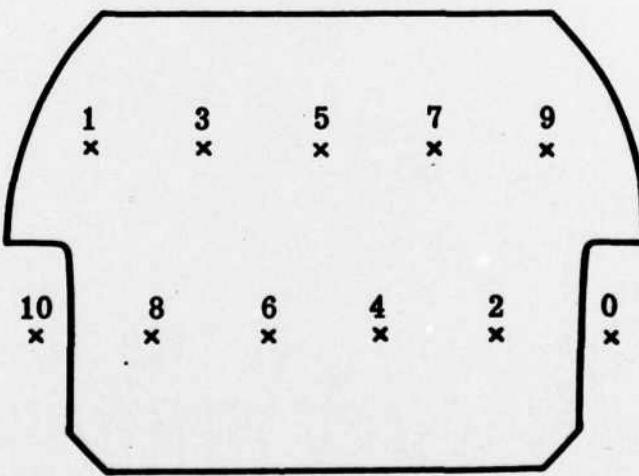


Figure 9. White Cell Image Pattern

**at the exit (point 10 in Figure 9) to return the beam back through
the White cell for twice the normal number of passes.**

4. CALIBRATION

This instrument is designed to measure the integrated water vapor over a 5 km path for amounts of water vapor expected in the atmosphere. However, for reasons of convenience the instrument is calibrated in grams per cubic meter of water vapor. This choice along with other design considerations eliminates most of the effects of atmospheric temperature. If the instrument were calibrated in terms of torr or another pressure unit, different calibration curves would be necessary for different atmospheric temperatures. This is because the water vapor number density for a given pressure varies with temperature. The g/m^3 units can be converted to torr of water vapor by using the fact that at 288.8 K, 1 torr is equivalent to $1 \text{ g}/\text{m}^3$ of normal water vapor.

Prior to construction of the GFCS the expected calibration signal was calculated. In Figure 10 this calculated signal is compared with the measured signal. The good agreement between these curves adds to the credibility of Table 5 which gives the calculated instrument sensitivity to atmospheric conditions.

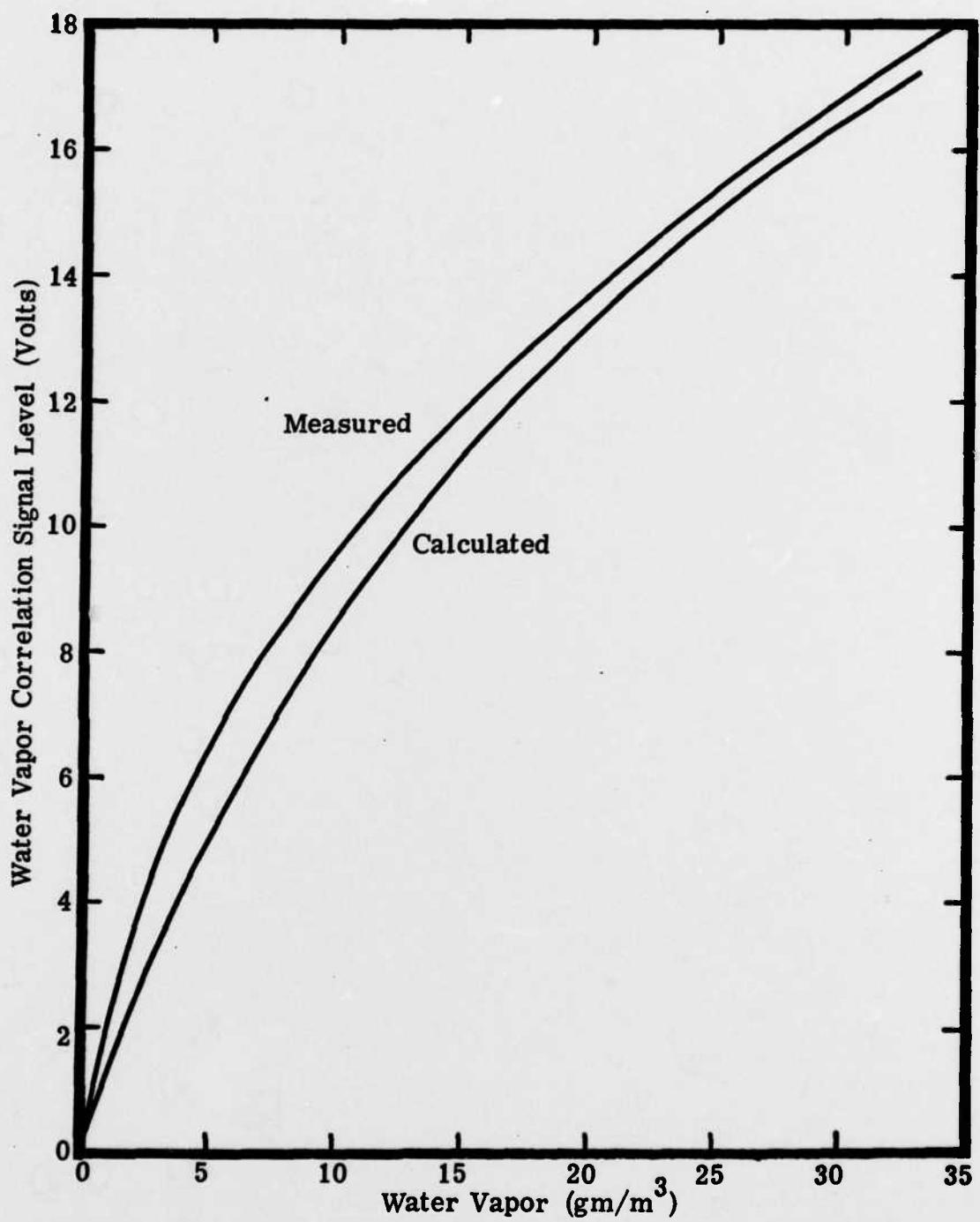


Figure 10. Calculated and Measured GFCS Response Curve

Table 5.
Changes in the Measured Water Vapor Density for
Given Changes in Atmospheric Conditions

Atmospheric Conditions	Atmospheric Water Vapor Density	2 gm/m ³	10 gm/m ³	20 gm/m ³	30 gm/m ³
Total Pressure	-1.06 in Hg (+1000')	+0.5%	-0.2%	-0.7%	-1.0%
Temperature	+10° C	-1.3%	-0.9%	-0.9%	-0.9%
Interfering Gases	N ₂ O	0.6%	0.3%	0.3%	0.3%
	CH ₄	-0.5%	-0.2%	-0.2%	-0.1%
	H ₂ O	0.2%	0.3%	0.5%	0.6%

